Nuclear Chemistry Notes

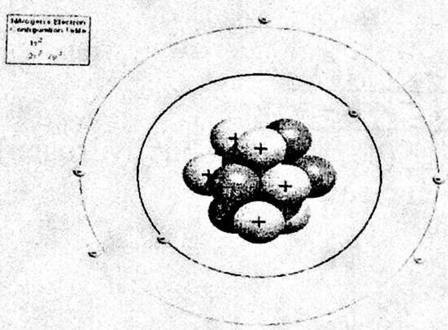
INTRODUCTION

- **Nuclear chemistry** – subfield of chemistry dealing with RADIOACTIVITY and nuclear processes, properties and reactions
- "Nuclear" = involving the NUCLEUS
  - Why do you care about nuclear chemistry? List at least 3 examples

→ GET POWER (NUCLEAR POWER PLANTS) – NO AIR POLLUTANTS
→ STERILIZATION OF MEDICAL TOOLS / X-RAY MACHINES
→ CANCER TREATMENT → GAMMA KNIFE – BRAIN TUMORS

REVIEW

The ATOM

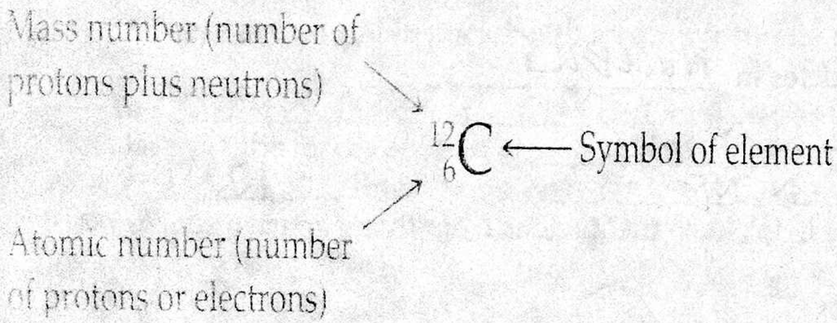


7P
7N
7E

a. What element is presented? NITROGEN

b. How do you know? There are 7 protons and electrons

The NUCLEUS



- The nucleus is comprised of PROTONS and NEUTRONS (called **nucleons**).
- The number of protons is the ATOMIC #.
- The number of protons and neutrons together is effectively the MASS of the atom.

ISOTOPES

- Not all atoms of the same element have the same mass due to different numbers of neutrons in those atoms.
- For example, the following are three naturally occurring isotopes for uranium:

–Uranium-234 Atomic number = 92 Neutrons = 142
–Uranium-235 Atomic number = 92 Neutrons = 143
–Uranium-238 Atomic number = 92 Neutrons = 146

NUCLEAR REACTIONS vs CHEMICAL REACTIONS/CHANGES

- Nuclear reactions involve the NUCLEUS (protons and neutrons) while "normal" chemical reactions involve ELECTRONS
- No matter which type of reaction or change, atoms like to become STABLE
- In a chemical reaction or in bonding, atoms achieve stability by filling their VALANCE electron shells (donate, accept, or share electrons)
- In nuclear reactions, atoms achieve stability by changes to their NUCLEI (emitting radiation)

WHAT HOLDS AN ATOM TOGETHER?

Answer – 2 FORCES

1. <u>Electrostatic forces</u>

–ATTRACTION AND repulsion between charged (e^- and p^+) particles

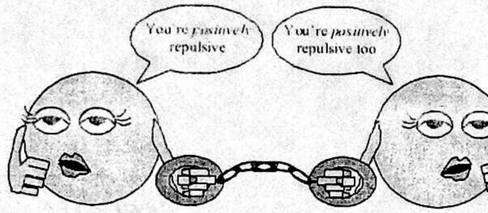
–Ex. e- and p^+ = ATTRACT

p^+ and p^+ = REPEL

–Strength of electrostatic forces: Short distances = STRONG

Long distances = WEAK

–Any element with more than one PROTON (i.e., anything but hydrogen) will have repulsions between the protons in the nucleus.



2. <u>Strong Nuclear force-</u>

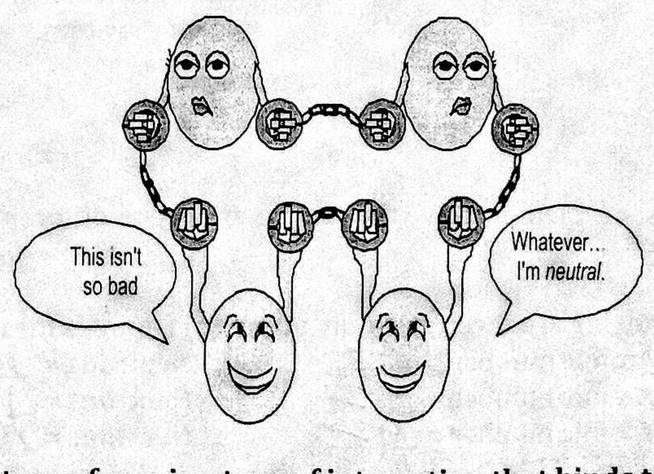
–Attraction between particles in NUCLEUS

–Strength:

Short distances = very STRONG

Long distances = NONE

–The strong nuclear force helps keep the nucleus from flying apart.



-The strong force is a type of interaction that binds together protons and neutrons in a nucleus. Without it, the positively charged protons would repel each other and blow the nucleus apart

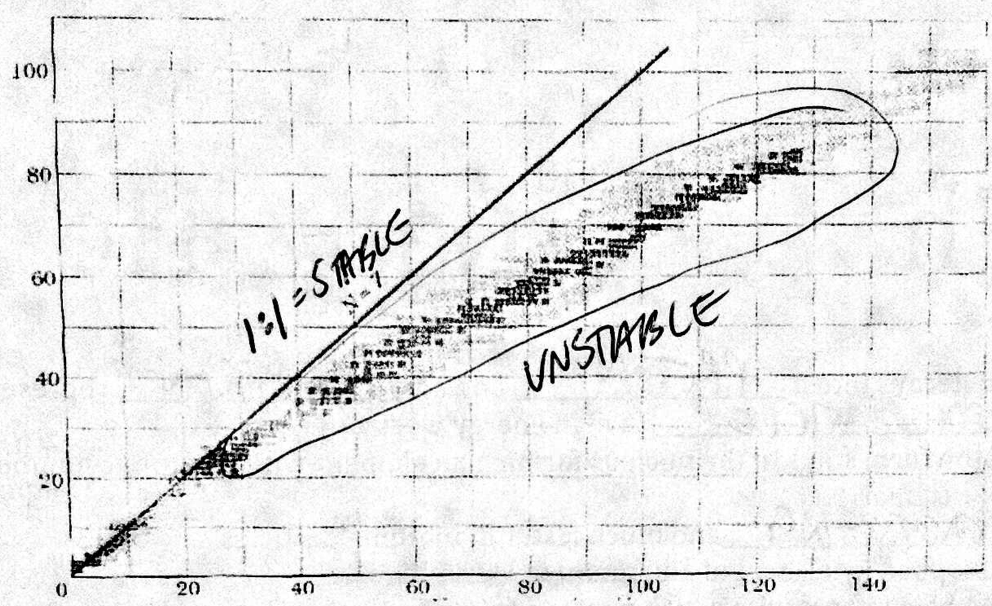
THE IMPORTANCE OF NEUTRONS

-Neutrons play a key role in STABILIZING the nucleus.

-Therefore, the ratio of neutrons to protons is an important factor.

-For smaller atoms (*Atomic Number* ≤ 20), stable nuclei have a neutron-to-proton ratio close to 1:1. As nuclei get larger, it takes a greater number of NEUTRONS to stabilize the nucleus.

-Anything lying below the "STABLE REGION" with too many neutrons will emit parts of the NUCLEUS in order to become STABLE.



*** There are no stable nuclei with an atomic number greater than 83

-The STRONG NUCLEAR FORCE diminishes as the nuclei become LARGER, but the electrostatic forces are just weaker. Without the strong nuclear force holding the NUCLEI together, electrostatic forces take over, like charges REPEL, and the nucleus decays, emitting RADIATION.

RADIATION

- Unstable nuclei are "RADIOACTIVE," meaning they emit radiation
- **Radiation** – the particles that are released from the NUCLEUS during radioactive decay
- **Radioactive decay** – BREAKDOWN of an unstable atomic nucleus into one or more different NUCLIDES

TYPES OF RADIOACTIVE DECAY

During emission, the atom can change into a different ATOM OR a different ISOTOPE.

There are several ways nuclei can decay. We will focus on:

1. ALPHA 2. BETA 3. GAMMA

RADIATION

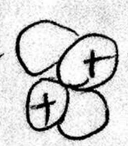
α

Alpha Decay

- Loss of an ALPHA PARTICLE (a helium nucleus, no electrons)
- Least penetrating
- LARGEST and SLOWEST form of radiation
- Can be stopped by a piece of paper
- Deadly if released by atoms inside your body
- Common in elements with atomic numbers > 83

Alpha Particle:

$^{4}_{2}He$



$$^{238}_{92}U \longrightarrow {}^{234}_{90}Th + {}^{4}_{2}He$$

$$^{244}_{94}Pu \longrightarrow {}^{240}_{92}U + {}^{4}_{2}He$$

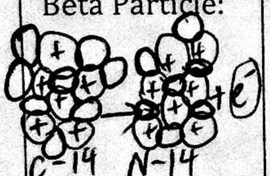
$$^{234}_{90}Th \longrightarrow {}^{230}_{88}Ra + {}^{4}_{2}He$$

Beta Decay

β

- Neutron decays into a PROTON and an ELECTRON representing the loss of a BETA PARTICLE (a high energy electron)
- The proton form stays in the nucleus forming an element with an atomic number 1 greater than the original
- More PENETRATING and much faster than Alpha particles
- Can be stopped by a sheet of aluminum foil
- Common in elements with a high neutron-to-proton ratio, which are below the stable region

Beta Particle:



$$^{131}_{53}I \longrightarrow {}^{131}_{54}Xe + {}^{0}_{-1}e$$

$$^{84}_{35}Br \longrightarrow {}^{84}_{36}Kr + {}^{0}_{-1}e$$

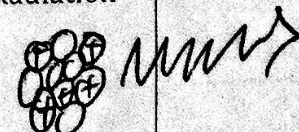
$$^{234}_{90}Th \longrightarrow {}^{234}_{91}Pa + {}^{0}_{-1}e$$

Gamma Emission

- Loss of a GAMMA RAY γ (high energy radiation that almost always accompanies the loss of a nuclear particle
- No mass and no charge
- Travels at the speed of light
- Most penetrating
- Lead and concrete are used at barriers

Gamma Radiation

$^{0}_{0}\gamma$



Measuring Radioactivity

One can use a device like a GEIGER counter to measure the amount of activity present in a radioactive sample.

Radioactive Decay Rates

Radioactive decay depends on the PROTON to NEUTRON ratio. An atom is generally stable if the ratio is about 1:1

Half-life: the TIME in which HALF of a radioactive substances decays

- Different isotopes have different half-lives; some are nanoseconds and others are billions of years

Common Radioactive Isotopes

PERFECT ½ LIFE FOR DATING FOSSILS →

Isotope	*Half-Life*	*Radiation Emitted*
Carbon-14	5,730 years	β, γ
Radon-222	3.8 days	α
Uranium-235	7.0×10^8 years	α, γ
Uranium-238	4.46×10^9 years	α

How does half-life work?

Classroom Example: half life = 30 seconds

	Time = 0 s	Time = 30 s	Time = 60 s	Time = 90 s	Time = 120 s
Number of students	400	200	100	50	25

Radioactive Half-Life

- After one half life there is 1/2 of original sample left.
- After two half-lives, there will be 1/2 of the 1/2 = $\frac{1}{4}$ the original sample
- After three half-lives, there will be ½ of ½ of ½ = $\frac{1}{8}$ of the original sample
- What fraction of the sample will be left after "n" half- lives? $\left(\frac{1}{2}\right)^n$
  - Example: What fraction of the original sample will be left after 4 half lives? $\frac{1}{16}$

Radioactive Decay Rates

Use of isotopes with known half-lives:

1. Geologists calculate the age of rocks
2. Archaeologists determine the age of fossils and artifacts
3. Nuclear medicine

Radium-226 ½ life of 1599 years 7/8 to decay

(3 half lives pass) 1/8 left) 1599 +1599 +1599 4,797 YEARS

Half-Life Practice Problems

A sample of strontium-90 is found to have decayed to 1/8 of its original amount after 87.3 years. What is the half-life of strontium-90?

$\frac{1}{8}$ LEFT - 3 ½ LIVES PASSED 3|87.3 = 1 HALF LIFE = 29.1 YEARS

Transmutation

- Process of changing one ELEMENT to another through NUCLEAR decay.
- Isotopes that give off ALPHA and BETA particles undergo transmutation.

Energy in Nuclear Reactions

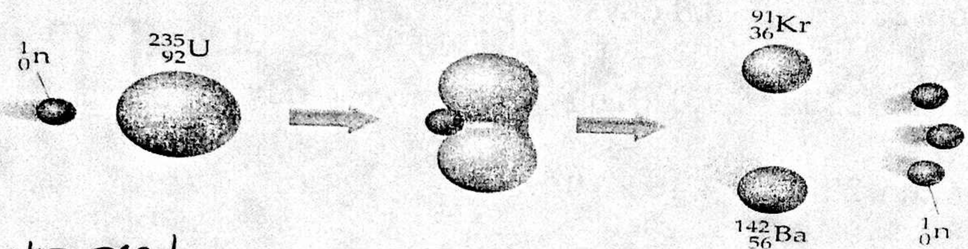
- There is a *tremendous* amount of ENERGY stored in NUCLEI.
- In CHEMICAL reactions the amount of MASS converted to energy is minimal.
- However, these energies are many THOUSANDS of times greater in nuclear reactions.
  - Example: 1 atom splitting is 6,700,000x's more energetic than ONE molecule of TNT exploding.

Nuclear Fission (splitting the nucleus of an atom)

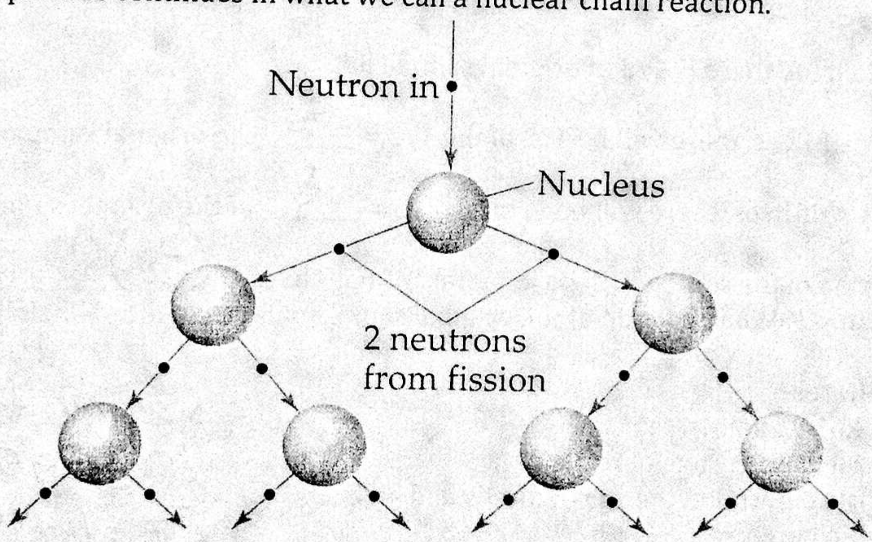
- Nuclear fission is the type of reaction carried out in nuclear reactors to harness this energy.

$$^{1}_{0}n + ^{235}_{92}U \rightarrow ^{137}_{52}Te + ^{97}_{40}Zr + 2\,^{1}_{0}n$$

$$^{1}_{0}n + ^{235}_{92}U \rightarrow ^{142}_{56}Ba + ^{91}_{36}Kr + 3\,^{1}_{0}n$$



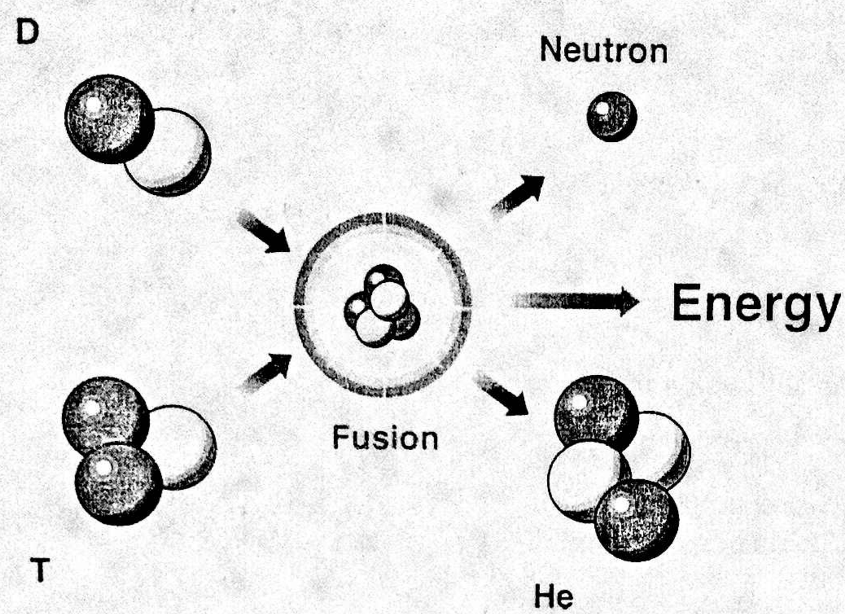
- A NEUTRON is used to bombard a heavy nucleus, which causes a SPLIT of that nucleus into 2 fragments, a release of NEUTRONS, and a release of ENERGY.
- Nuclear Fission can lead to a NUCLEAR CHAIN REACTION
  - The neutrons released in a fission reaction can start a chain reaction.
  - The neutrons released in the transmutation process can strike other NUCLEI, causing their decay and the production of more NEUTRONS.
  - This process continues in what we call a nuclear chain reaction.



- Chain reactions must be sustained with a CRITICAL MASS
  - If there are not enough RADIOACTIVE nuclides in the path of the ejected neutrons, the chain reaction will die out.
  - Therefore, there must be a certain MINIMUM amount of FISSIONABLE material present for the chain reaction to be sustained: CRITICAL MASS.

Nuclear Fusion (combining nuclei)

- 2 light nuclei combine to form a HEAVIER nuclide releasing LOTS of ENERGY.
- Fusion powers the STARS (including the sun)
- Fusion would be a superior method of generating power.
    - The good news is that the products of the reaction are not radioactive.
    - The bad news is that in order to achieve fusion, the material must be in the plasma state at several million Kelvins. (Room temperature = about 23 Kelvins).



Nuclear Radiation Today

- You are exposed to nuclear radiation everyday. Some forms are harmful, others beneficial
- BACKGROUND RADIATION – the nuclear radiation that arises naturally from the sun, soil, rocks, and plants
- About 80% of our daily exposure comes from these sources…the other 20% comes from human-made sources (computers, smoke detectors, X-Rays)
- Levels of radiation absorbed by the human body are measured in REMS or millirems (1 rem = 1000 millirems)
- Safe limit = 5,000 millirems on top of background exposure
- Amount of exposure to natural radiation depends on location